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Nanoscale Thermal Imaging of Dissipation in Quantum Systems and in Encapsulated Graphene

Electron Physics Group Seminar

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Energy dissipation is a fundamental process governing the dynamics of physical systems. In condensed matter physics, in particular, scattering mechanisms, loss of quantum information, or breakdown of topological protection are deeply rooted in the intricate details of how and where the dissipation occurs. While the motivation is clear, existing thermal imaging methods lack the necessary sensitivity and are unsuitable for low temperature operation required for study of quantum systems. Recently, we developed a novel technique for imaging of dissipation, the scanning nano-SQUID on tip thermal microscopy. It provides a thermal sensitivity of less than 1 $\mu K\sqrt{Hz}$ with a sub 50 nm spatial resolution. The non-contact non-invasive thermometry scheme allows thermal imaging of very low nanoscale energy dissipation down to the fundamental Landauer limit of 40 fW for continuous readout of a single qubit at 1 GHz at 4.2 K. Furthermore, it is optimal for low temperature applications. These advances enabled the observation of dissipation due to single electron charging of individual quantum dots in carbon nanotubes, opening the door to direct imaging of nanoscale dissipation processes in quantum matter. The technique was utilized to visualize and control the local release of heat, by manipulating individual atomic defects and identifying the dominant dissipation pathway in clean graphene heterostructures. We directly observed resonant inelastic scattering at such defects and determined their spectral characteristics. Originating from highly-localized states near the Dirac point, the defects act as switchable phonon emitters providing energy sinks when the Fermi level comes in resonance with defects' energy levels.

Further reading:
[1] D. Halbertal et al., 'Nanoscale thermal imaging of dissipation in quantum systems', *Nature* **539**, 407 (2016).
[2] D. Halbertal et al., 'Imaging and controlling dissipation from individual atomic defects in graphene', under review (2017).
[3] D. Halbertal, PhD thesis, Weizmann Institute of Science (2017).

Speakers

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